AEDC-TR-91-9

C. 3

Calibration of an AEDC Low-Temperature Blackbody Standard at NIST

K. B. Jarratt
Calspan Corporation/AEDC Operations

January 1992

Final Report for Period February 1990 through June 1991

Approved for public release; distribution is unlimited.

ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE BASE, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

NOTICES

APPROVAL STATEMENT

This report has been reviewed and approved.

SETH D. SHEPHERD, Capt, USAF
Flight Dynamics Division
Directorate of Technology
Deputy of Operations

Approved for publication:

FOR THE COMMANDER

Keith L. Kushman

KEITH L. KUSHMAN
Director of Technology
Deputy for Operations

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1992	Final, February 1990 -- June 1991

4. TITLE AND SUBTITLE
Calibration of an AEDC Low-Temperature Blackbody Standard at NIST

5. FUNDING NUMBERS
PE-65807F
PN - DD43VL

6. AUTHOR(S)
Jarratt, K. B., Calspan Corporation/AEDC Operations

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Arnold Engineering Development Center/DOT
Air Force Systems Command
Arnold Air Force Base, TN 37389-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
AEDC-TR-91-9

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
Arnold Engineering Development Center/DO
Air Force Systems Command
Arnold Air Force Base, TN 37389-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available to Defense Technical Information Center (DTIC).

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Low-temperature blackbody sources that emit in the long-wavelength infrared were calibrated to a standard at the National Bureau of Standards (NBS) through mid-1984, at which time this service was discontinued. In late 1989, the National Institute of Standards and Technology (NIST), formerly the NBS, reestablished this capability. AEDC was the second customer at the new facility and obtained a calibration of a 400 K, multiple aperture blackbody in February 1990. This report provides a description of the source and associated instrumentation sent to NIST, guidelines for preparing a source for going to the NIST facility, and summarizes the calibration results for the AEDC blackbody.

14. SUBJECT TERMS
radiometric calibration
blackbody radiation
low temperature
infrared equipment
high vacuum

15. NUMBER OF PAGES
26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

PREFACE

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC). The results were obtained by Calspan Corporation/AEDC Operations, operating contractor for Aerospace Flight Dynamics testing at the AEDC, AFSC, Arnold Air Force Base, TN, under AEDC Project Number DD43VW, Calspan Project Number V32L-FD. The Air Force Project Manager was Capt. Seth Shepherd, AEDC/DOTF. This report describes work initiated in February 1990 and completed in June 1991. The manuscript was submitted for publication on January 2, 1992.

CONTENTS

ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

Sensors and their focal planes that are responsive to long-wavelength infrared (LWIR) energy and operate in a low-pressure environment require calibration. Calibration is normally accomplished in a vacuum chamber having an optically tight, cryogenically cooled liner. A blackbody source or attenuated blackbody source is used in the chamber to provide a known level of LWIR energy to the sensor or focal plane. Prior to the test, these blackbodies must also be calibrated.

Low-temperature blackbody sources that emit in the LWIR were calibrated to a standard at the National Bureau of Standards (NBS) through mid-1984, at which time this support was discontinued. At AEDC, establishing source radiometric output was then accomplished by transferring calibrations from a source with a previous NBS calibration. In late 1989, the National Institute of Standards and Technology (NIST), formerly the NBS, began operation of their low background infrared (LBIR) calibration facility. AEDC was the second customer at the new facility and obtained a calibration of a 400 K, multiple aperture source in February 1990. The final calibration report was received from NIST in February 1991.

This report describes the source assembly and associated instrumentation that were sent to NIST. A guideline for the preparation and integration of the source into the NIST facility is also included. In addition, this report will provide a summary of the calibration results for the AEDC blackbody. It will provide a reference of the calibration for users of the blackbody, since the NIST calibration report is not available through the Defense Technical Information Center (DTIC).

2.0 LWIR SOURCE PACKAGE

The LWIR source package that was shipped to NIST in January 1990 for calibration was a composite of old and new hardware. The blackbody core assembly, fabricated at AEDC in 1983, was originally a part of a single aperture blackbody assembly that was shipped to the NBS for calibration. However, this calibration was not completed because of equipment problems at the NBS and lack of financial backing for the replacement and upgrade of their calibration equipment. When NIST reestablished a capability for low radiometric background infrared source calibration in early FY90, this old model core assembly was integrated with a new multiple aperture housing assembly developed for focal plane array testing at AEDC (Ref. 1). Since 1983, many improvements have been made to the blackbody core assembly design to increase the temperature range to 500 K, to minimize outgassing of fabrication materials, and to improve the thermal isolation of the core. The following is a description of the source as shipped to NIST and does not include the latest design changes.

2.1 BLACKBODY ASSEMBLY

The blackbody source is a multiple aperture version of our original standard infrared source (SIRS) configuration designed and fabricated at AEDC (Ref. 2). This multiple aperture blackbody is referred to as SIRS II. The source was designed to operate to a maximum temperature of 400 K and uses apertures to 0.100 in. Figure 1 shows the cross-sectional view of the SIRS II. The blackbody emitter is a reentrant conical cavity design. The emitter material is 6061-T6 aluminum. The interior cavity surfaces were roughened uniformly using electrical discharge machining techniques. The entire emitter assembly was black anodized to produce a highly emissive surface and to provide electrical insulation to the heater winding. The total emittance of the cavity by calculation and surface reflectance measurements is greater than 0.99 over the wavelength range of 2 to 30 μm. The exterior surfaces of the front cap of the emitter, which contains the reentrant part of the cone, were highly polished to reduce the radiant load on the field stop and output aperture. Only the interior of the conical cavity can be viewed through the output aperture. The emitter output overfills the internal 0.177-in.-diam field stop at the cavity exit. The distance from this internal aperture to the output aperture is 0.250 in.

A platinum wire heater, 0.005 in. in diameter, is wound around the cavity to heat it to the desired operating temperature (from 100 to 400 K). It was secured with Fiberglas® thread that was afterwards impregnated with a high-temperature paint. Copper extension leads extend the heater wires to the electrical connector.

Cavity temperature is measured using two platinum resistance temperature devices (RTDs) potted deep into the blackbody emitter adjacent to the conical cavity using a high-temperature epoxy. The RTDs were used in a four-wire configuration. Lead wires were constantan and were silver soldered to the platinum leads of the each RTD. Having two sensors provides a redundant readout for measurement system trouble shooting. The two sensors normally agree within 0.1 degree when the source is at an isothermal condition. The calibration data are directly tied to the resistance of these sensors.

Thermal isolation and mechanical support of the emitter is accomplished by use of low-conductivity, thin-wall stainless steel tubing. As shown in Fig. 1, two stainless steel tubes connect the core mounting arbor to the base mounting flange. This mounting flange is attached to the housing, which normally operates at temperatures below 20 K.

Output apertures are mounted on a wheel that is directly coupled to a stepper motor. This wheel contains six apertures and a blank (no output) position. The blank position provides a zero-output condition for evaluation and correction of background effects. The range of source output aperture sizes provides a factor of 400 range in source intensity. The aperture

sizes are listed in Table 1 versus an aperture wheel position number. The apertures were manufactured by Buckbee Mears Co. with nominal diameters listed in the left-hand column. The holes were observed to be slightly out-of-round as determined by measuring the diameters every 120 deg. The average of the three measurements was used as the actual diameter, and the standard deviation of these measurements was used as the uncertainty of that dimension. The output apertures are made of 0.003-in.-thick copper with a thin layer of nickel on one side in which the aperture orifice is formed. The copper was assumed to be pure and to dominate the thermal contraction of the aperture opening. The thermal contraction from ambient to 20 K was calculated to be −0.324 percent for each aperture. Reference 3 details the methodology used to calculate the contraction, and the values obtained for each aperture appear in Table 1.

The aperture wheel is positioned with a direct-coupled stepper motor. It is driven in a full-step mode which provides a step angle resolution of 1.8 deg. The apertures were aligned to the full-step positions of the motor with 7 steps between each aperture. The accuracy of positioning the wheel is determined by the full-step accuracy of the motor, typically 3 percent of step angle. A continuous turn potentiometer and an optical interrupter module consisting of a light emitting diode (LED) and a phototransistor was used in combination to select the appropriate full-step position for each aperture. The potentiometer determines the general rotational position or window for a particular aperture. Within that window, a narrow slit in the wheel, corresponding to each aperture position, allows light from the LED to illuminate the phototransistor. This activates the phototransistor, which generates a halt signal to the wheel controller.

Cooling of the aperture wheel is accomplished by the use of a copper braid cooling strap attached to the wheel and to the 20 K housing. The wheel is thermally decoupled from any motor heating because of the low conductance of the stainless steel motor shaft. Motor heating is insignificant (less than 2 K increase) when the motor current is left on. The reduction in motor winding resistance at low temperatures minimizes the resistive heating. Also, inductive heating is minimized by the use of a linear, current-controlled output stage on the stepper motor driver.

2.2 INSTRUMENTATION

Instrumentation for monitoring and control of the source unit includes an aperture wheel control, IR source monitor, and temperature controller. Temperature sensor voltages, sensor excitation current, heater voltage, and current were monitored by the NIST data system through a patch panel provided. This instrumentation was mounted in a portable instrument rack for shipment to NIST (Fig. 3). The RTDs used in the emitter of the blackbody are platinum-wire-wound elements that measure nominally 100 ohms at 273.15 K. These units were calibrated

by the AEDC Precision Measurement Equipment Laboratory (PMEL). Another temperature sensor was placed on the electrical connector plate. This location was chosen because it was believed to be the component with the slowest temperature response. This sensor was used to indicate when calibration base temperature had been achieved. The sensor used at that location is a composite manganin-nickel RTD with a nominal room temperature (295 K) resistance of 290 ohms. At 15 K, it reads nominally 223 ohms. Emitter RTDs, indicated as Sensors A and B on the IR source monitor, and the base temperature RTD, indicated as Sensor C, are serialized K95, K97, and R2A91, respectively. Table 2 gives the temperature versus resistance for each RTD.

The aperture wheel control chassis allows the user to select one of seven aperture wheel positions. The basic operation of the chassis consists of selecting the desired aperture position using the rotary switch and then executing the move using the "Move To Aperture" switch. The "Aperture Position" LEDs indicate the current position of the aperture wheel. The chassis provides the ability to single step or continuous run the drive motor in either the clockwise or counterclockwise direction. The clockwise direction corresponds to increasing aperture position. There are seven motor steps between each aperture position. Current is applied to the aperture wheel drive motor through the use of the "Motor Current" off/on switch. The current is left on during bakeout of the source and then turned off during cooldown. During normal operation, the motor current is left on. At 20 K, there is little power dissipation when the current is left on and the wheel is not being actuated. The panel meter indicates the amount of current in amperes. The nominal amount of current delivered to the motor is 2.4 amp; however, a "Motor Current Boost" switch is located on the back of the chassis for delivering 3.6 amp if any sticking of the aperture wheel occurs.

The IR source monitor chassis provides signal isolation from the cavity platinum RTDs to the temperature controller, supplies excitation to the three temperature sensors, and provides fail-safes to prevent an overtemperature or overpower condition to the blackbody emitter. Monitoring of the temperature sensor voltages, current excitation, and heater power is provided through an output connector, and for use at NIST, a BNC patch panel. The digital panel meter can be used to monitor the temperature sensor voltages for setpoint conditions, but is not used to record calibration data. The operation of this chassis includes turning on the AC power, and then heater current once the temperature controller has been properly configured. The failure reset switch is used to clear one of the failure modes after the condition has been corrected.

The temperature control used was a Lake Shore Cryotronics model DRC-82C. The temperature control is a digital readout, 3-term (gain, rate, reset) analog control. It has two displays allowing it to monitor both platinum RTDs simultaneously. To operate, the a-c power is turned on after the IR source monitor is turned on. The gain, rate, and reset values are

set. The values 80, 20, and 60, respectively, were chosen as good starting points for setup. The setpoint was then selected. The maximum d-c current output was set to just maintain control.

When the source is prepared for cryogenic background operation, it is necessary to heat the source cavity to its maximum operating temperature of 400 K for an extended period as determined by the chamber pumping speed, volume, outgassing, etc. During this period, the d-c current is left on to the aperture wheel control, and the aperture wheel is left in Position 3, which is the largest aperture. The a-c power to the motor control is left on upon completion of installation and until the chamber is warmed up for removal of the source. If the base-mounting temperature of the source were ever to exceeded 330 K, a failure would be indicated on the IR source monitor panel. This indication cannot be reset until the condition is cleared.

3.0 PREPARATION OF SOURCE PACKAGE FOR NIST LBIR CALIBRATION

3.1 STEPS IN THE NIST CALIBRATION PROCESS

The calibration was performed at the NIST LBIR calibration facility. The following is a summary of the steps in the LBIR calibration process. First, a written request is sent to the director of the NIST facility. This letter should describe the blackbody to be calibrated including the temperature range, temperature increments, and number of apertures required. The letter should also indicate the desired time slot for completing the calibration. Next, a purchase order is to be sent to NIST. There is a standard fee of $5,000 for calibrations lasting less than 4 weeks. This fee covers the costs of expendable materials used during the calibration. The actual cost of the facility and personnel is currently subsidized by the Army's Strategic Defense Command. Upon receipt of a purchase order, NIST supplies a blackbody mounting plate and electrical connectors to mate to the LBIR chamber along with a wiring diagram of the electrical feedthroughs available. The user is responsible for mounting the blackbody aperture with respect to the optical axis of the mounting plate as well as determining the distance from the source aperture to an Invar® reference tab (both at ambient and 20 K). The user must provide both inside and outside cables for hookup of the blackbody assembly. The blackbody is then shipped to NIST in Gaithersburg, MD, along with all necessary instrumentation, controls, and cables. Detailed instructions for interfacing and operating the blackbody must be included. It is recommended that a user representative be present for the initial installation of the blackbody. The blackbody checkout and calibration begins with the blackbody and mounting plate being bolted to the LBIR chamber actively cooled plate. Initial checkout of wiring and controls is then performed at ambient temperature in air. The auxiliary chamber is installed and pumped out. After pumping to approximately 10^{-7} torr total pressure, residual gas analysis is performed. The partial pressure of hydrocarbon peaks should not exceed 1×10^{-10} torr. After checkout of the blackbody, the

auxiliary chamber is removed and the blackbody is installed in the main chamber. Distance between the mounting reference tab and the Kaman proximity sensor is noted. Pumpdown of the chamber is completed and additional residual gas analysis is performed. Cooldown using 15 K helium gas is then begun. The actively cooled plate and inner cryoshield reach 20 K in approximately 3 days. After the chamber liner and blackbody assembly are cooled, the absolute cryogenic radiometer (ACR) is cooled to 4 K with liquid helium. Pumping on the dewar is then required to achieve its 2 K operating temperature. The ACR is scanned approximately ± 0.250 in. in the horizontal direction to peak the signal received from the blackbody. A minimum of three complete data sets is completed before the chamber is warmed up and vented. The blackbody is then returned freight collect per the user's instructions. The calibration report is written and sent to the user along with an invoice approximately 4 to 6 weeks after completion of the calibration.

3.2 FACILITY DESCRIPTION AND CONDITIONS FOR CALIBRATION

The LBIR chamber and the ACR are described in detail in the SPIE publication entitled "Update on the Low-Background IR Calibration Facility at the National Institute of Standards and Technology," (Ref. 4). Basically, the LBIR chamber is a ultra-high vacuum chamber, operating at 10^{-9} torr pressure. It contains an optically tight gaseous helium-cooled liner that is cooled to below 20 K. The blackbody to be calibrated is positioned within the cold liner so that it directly projects on the ACR through several cold field stops. The ACR is a liquid helium-cooled electrical substitution radiometer designed for highly repeatable and accurate measurements of broadband incoherent radiation.

3.3 INTEGRATION OF AEDC HARDWARE

The source assembly was mounted on a gold-plated copper mounting plate which was provided to AEDC by NIST and modified at AEDC to include the blackbody mounting spacer and a blackened shroud to minimize stray background energy. This assembly with the blackened shroud removed is shown in Fig. 2. The mounting spacer placed the blackbody aperture on the LBIR chamber optical centerline. The blackened shroud was provided to ensure that the ACR could only see the blackbody aperture, and that within the remaining portion of its field-of-view, it only saw a cold absorbing surface. The source output aperture was positioned 2.451 in. from the reference surface on the plate. The reference surface was an Invar tab installed at the right front corner of the base of the blackbody mounting plate. This distance was measured to the nearest thousandth of an inch. To determine the final separation of the blackbody aperture and the ACR, thermal contraction of the mount was taken into consideration. The front blackbody mounting screws were located 2.938 in. from the front of the NIST-supplied mounting plate. The source housing and base mounting block were fabricated from 6061-T6 aluminum. The distance from the front mounting screws to the front of the aperture wheel is 0.500 in.

Electrical connectors and instructions for wiring the blackbody control cables were provided by NIST. Inside and outside cables were fabricated at AEDC. Care was taken to ensure that the cables were not in the view of the ACR and that lead sizes were appropriate to minimize the thermal conductance and thermal mass of the leads. All of these factors could potentially contribute to a high radiometric background being seen by the ACR.

Data were supplied to NIST that included blackbody source physical data for use in determining the source performance. This information included the dimensions and uncertainties for the source geometry, thermal contraction effects, temperature sensor calibration, and the output aperture distance from the mounting plate reference tab. Instructions for the source operation were also included. A copy of all required temperature sensor data files was provided on an MS-DOS formatted floppy disk along with a software program DH.EXE that was used for the conversion of temperature sensor resistances to Kelvin units. Tabulations of resistance versus temperature for these temperature sensors were provided. A center-weighted 4-point Lagrangian interpolation was used to minimize curve-fit errors.

Blackbody data were collected by a data system consisting of a system multimeter, Hewlett-Packard Model HP3457A with a 10-channel multiplexer, and controlled by a personal computer through an IEEE-488 bus interface. Temperature sensor resistance was calculated by dividing the sensor voltage by the current excitation sense voltage and multiplying the result by a current sampling resistor resistance. The current sampling resistances were as follows:

Sensor A	1002.095 ohms
Sensor B	1001.421 ohms
Sensor C	1001.267 ohms

Heater power applied at a steady-state temperature condition was measured and calculated by the product of the heater voltage and current sampling voltage. This was recorded for each data point. Heater power is used as an indicator of the condition of the blackbody. Power dissipation should be the same each time a particular temperature setpoint is repeated.

4.0 NIST CALIBRATION RESULTS

The author was present at the NIST LBIR facility during source installation and initial operation. This allowed for confirmation that the blackbody operated in a similar manner as it did in the calibration chamber at AEDC. The blackbody assembly was first tested in the auxiliary chamber for vacuum compatibility with the specifications of the LBIR chamber. It passed the evaluation criteria. These criteria are about two orders of magnitude lower

pressure than that required for operation in test chambers at AEDC. The blackbody was installed in the main chamber, which was evacuated to 10^{-8} torr and cooled to 20 K (inner shield) by the closed cycle helium refrigeration system. The temperatures of the cold plate supporting the blackbody, the isothermal plate that has the shutter arrangement, and various other parts of the chamber were monitored continuously by strategically located silicon diode temperature sensors. The temperature data were collected before and after each set of radiant power measurements. The data were stored on disks along with the data from the blackbody RTDs. The temperature of the isothermal plate and the shutter in front of the ACR was actively maintained at 20 K and did not deviate by more than ± 0.5 K. The blank position of the aperture wheel was then used to measure the power at the ACR with the radiation from the blackbody blocked off.

A schematic indicating the dimensions involved in the calibration setup is given in Fig. 4. A Kaman proximity sensor system was used to measure the distance between the blackbody aperture and the ACR aperture at the ambient room temperature. The ambient temperature dimensions were adjusted to 20 K values by accounting for the contraction of materials. The optical alignment of the ACR to the blackbody was fine-tuned by operating the ACR as a bolometer and translating it laterally (micrometer adjustment) to maximize the detected signal caused by the blackbody radiation.

The total radiant flux was measured by the ACR in its active mode for each temperature setting of the blackbody and each of the six aperture settings. Prior to each flux measurement, the background flux was measured with the aperture wheel positioned to the blank (no output) position. The background flux was subtracted from the measured flux to obtain the radiant flux from the blackbody. Because of the limitations of the signal-to-noise ratio, it was not possible to measure irradiance values corresponding to a power on the ACR aperture below 40 nW and stay within 1-percent uncertainty for the measurement of radiance temperature. The ACR data were collected by reading the electrical parameters every sec for a 3-min period. These raw data points of radiant power, their average value, and the standard deviation were recorded as a separate computer file for each blackbody temperature and aperture setting. Each data point of radiant power was converted to the radiance temperature of the blackbody, and all the data for radiance temperatures, their average value, and the standard deviation were also stored on disks as a separate computer file for each blackbody temperature. This procedure of data collection was repeated three times for all apertures and required temperatures that gave a power on the ACR aperture that was 40 nW or above.

The following equation deduced from the Stefan-Boltzman law was used to convert radiant power data into radiance temperatures.

$$T = \left[\frac{E}{F_1 A_1 \sigma}\right]^{1/4} \tag{1}$$

where

$$F_1 = 1/2\left[z - \left(z^2 - 4\,x^2y^2\right)^{1/2}\right]$$

and where

$$x = \frac{r_2}{s},\ y = \frac{s}{r_1},\ z = 1 + \left(1 + x^2\right) y^2$$

r_1 is the radius of the blackbody aperture
r_2 is the radius of ACR aperture
s is the distance between apertures
A_1 is the area of the blackbody aperture
E is the power in watts
σ is the Stefan-Boltzman constant (5.67032×10^{-12} W cm^{-2} K^{-4})

The expression for the configuration factor, F_1, given in Eq. (1) was taken from Ref. 5. Its value was determined from the values of the quantities given as follows and the radii for the blackbody apertures given in Table 1. The measurements were made at room temperature and were adjusted to cryogenic temperatures by using the standard reference data for contraction of materials.

Radius of the ACR aperture at 2.2 K = 1.49711 cm.
Distance between the apertures at 20 K = 30.77 cm.

The ACR aperture diameter was measured at the Precision Engineering Division of NIST. The estimated error in this measurement was $\pm\ 5 \times 10^{-5}$ cm. The distance between the front surface of the reference tab and the ACR aperture was measured using vernier calipers and the Kaman measuring system. The estimated error in the measurement of the overall distance between the apertures is ± 0.042 cm. Standard theory of propagation of errors is used to obtain the systematic error in temperature measurement caused by errors in geometric measurements of distance between the apertures and the radii of the apertures.

Diffraction losses at each aperture in the beam path were estimated by using the procedures published in Refs. 6 and 7. The measured radiant flux values and the radiance temperatures were increased by using the correction factors for the total diffraction loss. The estimated systematic error in the calculated diffraction corrections, because of approximations used

in the diffraction calculations, was ±20 percent. This estimate has been questioned at AEDC because linearity data taken for the source apertures using a bolometer detector show that the correction is too high (Ref. 8).

The voltages across the blackbody RTDs for each blackbody temperature control setting were measured by the HP3457A model multimeter provided by NIST. They were recorded on a computer disk. The files were labeled with the first character as a letter (A, B, C, or D) indicating the successive repetitions of data collection, the second character as a digit (1, 2, 3, 5, 6, or 7) identifying the aperture setting, and the next three digits indicating the nominal temperature setting of the blackbody.

In each data file, there were 10 RTD sensor data points for each blackbody temperature setting. Each data point is an average of 10 readings with an integration time of 16.67 msec/reading. The data were collected in conjunction with the ACR data collection over a 3-min period after the ACR had stabilized. The mean voltages and currents and their standard deviations, measured for Sensor A and Sensor B, are identified clearly in the data file format. The voltages and currents measured for Sensors A and B were converted to resistance values using Ohm's law. User-provided multiplicative correction factors corresponding to the current sampling resistances were applied to the data. The corrected RTD resistance values were converted to temperature values by using the user-provided software program and the calibration data for each sensor. The temperature values for the 10 data points were averaged, and the standard deviation was calculated for each temperature setting of the blackbody.

All of the experimental data for the three repetitions of the blackbody temperature settings are presented in the NIST Report of Test. Copies of this report are kept on file at NIST, reference NIST Test No. 534/LBIR-2-90, and at AEDC. The measured total radiant flux at the ACR aperture for all blackbody apertures and temperature settings is reported. Calibration equations that provide radiance temperature as a function of measured emitter temperature were developed from the results of the test for each aperture. The estimated uncertainty in predicting the radiance temperatures by using the calibration equations was within the range of ±0.1 to ±0.7 percent. Table 3 gives representative results of calibration and indicates the quality of the blackbody. The first column is the temperature indicated by Sensor A, one of the platinum RTDs within the emitter. The second column is the radiance temperature calculated from the curve-fit equation for Sensor A provided by NIST. Since the blackbody broadband output is a function of temperature (T) to the fourth power, the deviation in radiance from an ideal blackbody is indicated by one minus the ratio of the indicated temperature to the radiance temperature raised to the fourth power. This is given in percent radiance in the third column. The NIST report gives uncertainty in terms of radiance temperature. The uncertainty in terms of power can be found by multiplying by a factor of 4, since temperature has a 4 times delta T over T dependence in the broadband equation

for radiance. This is given in the last column. The table shows that the output of the blackbody only deviates a small amount from an ideal blackbody. If no correction is made to the indicated temperature of the blackbody, then the output will be no greater than ±1.7 percent from the ideal value.

5.0 CONCLUSIONS

A transfer standard low-temperature, multiaperture blackbody was prepared at AEDC and sent to NIST for calibration. The calibration results indicate that the blackbody is within ±1.7 percent of what would be expected from an ideal blackbody over the temperature range of 200 to 400 K. NIST indicates an uncertainty in the calculated radiance temperature based on measurements of ±0.1 to ±0.7 percent over this range. As a result of this calibration, AEDC has reestablished its traceability to NIST in low-temperature blackbody flux. The new capabilities at NIST will allow further investigation of the validity of diffraction corrections now applied. It appears that these corrections are too high as a result of measurements at AEDC (Ref. 5). Improvements made in the ACR signal-to-noise ratio since this first AEDC calibration will allow measurements to be made at lower signal levels from small apertures where diffraction has a stronger effect.

Future use of the NIST facility will include repeat calibrations on low-temperature blackbodies to determine long-term stability, and calibration of higher temperature blackbodies.

REFERENCES

1. Nicholson, R. A. and Steele, C. L. "AEDC Focal Plane Array Test Capability." AEDC-TR-90-31 (AD-A230846), January 1991.

2. Sherrell, F. G. "Infrared Standards to Improve 7V Irradiance Calibration." AEDC-TR-80-45 (AD-A094658), October 1980.

3. Thermophysical Properties of Matter, The TPRC Data Series Volume 12, "Thermal Expansion: Metallic Elements and Alloys." IFI/Plenum, New York, 1975.

4. Ebner, S. C. and Parr, A. C. "Update on the Low-Background IR Calibration Facility at the National Institute of Standards and Technology." SPIE Vol. 1110 (1989).

5. Wyatt, C. L. *Radiometric System Design*. MacMillan, New York, 1987, pp. 37-38.

6. Steel, W. H., De, M., and Bell, J. A. "Diffraction Corrections in Radiometry." *Journal of the Optical Society of America,* Vol. 62, p. 1099.

7. Boivin, L. P. "Diffraction Corrections in the Radiometry of Extended Sources." *Applied Optics,* Vol. 15, p. 1204.

8. Young, R. P. "Application of Diffraction Corrections to Blackbody Sources." AEDC-TR-91-4 (AD-A237840), May 1991.

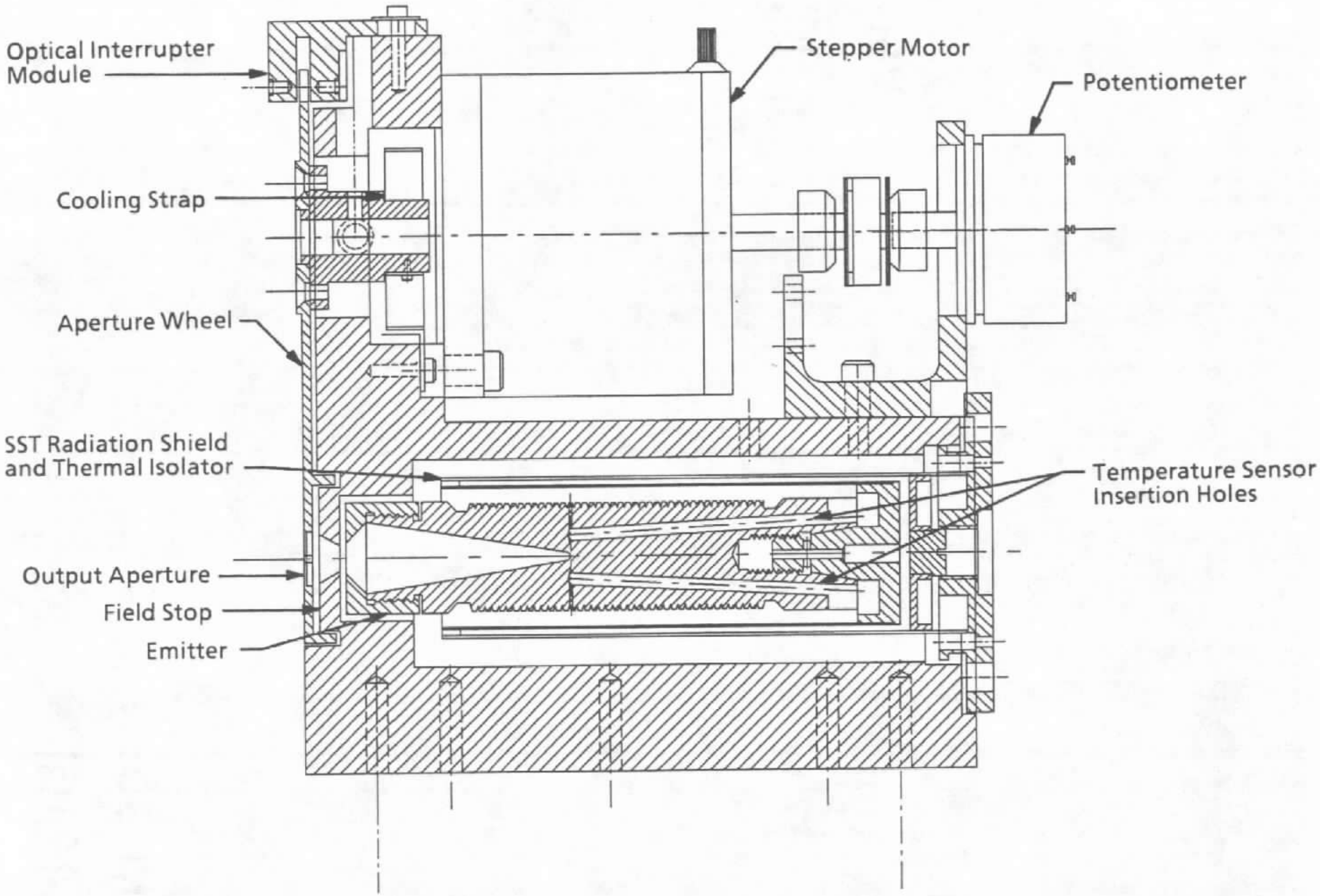


Figure 1. Standard Infrared Source (SIRS II) mechanical assembly cross-section view.

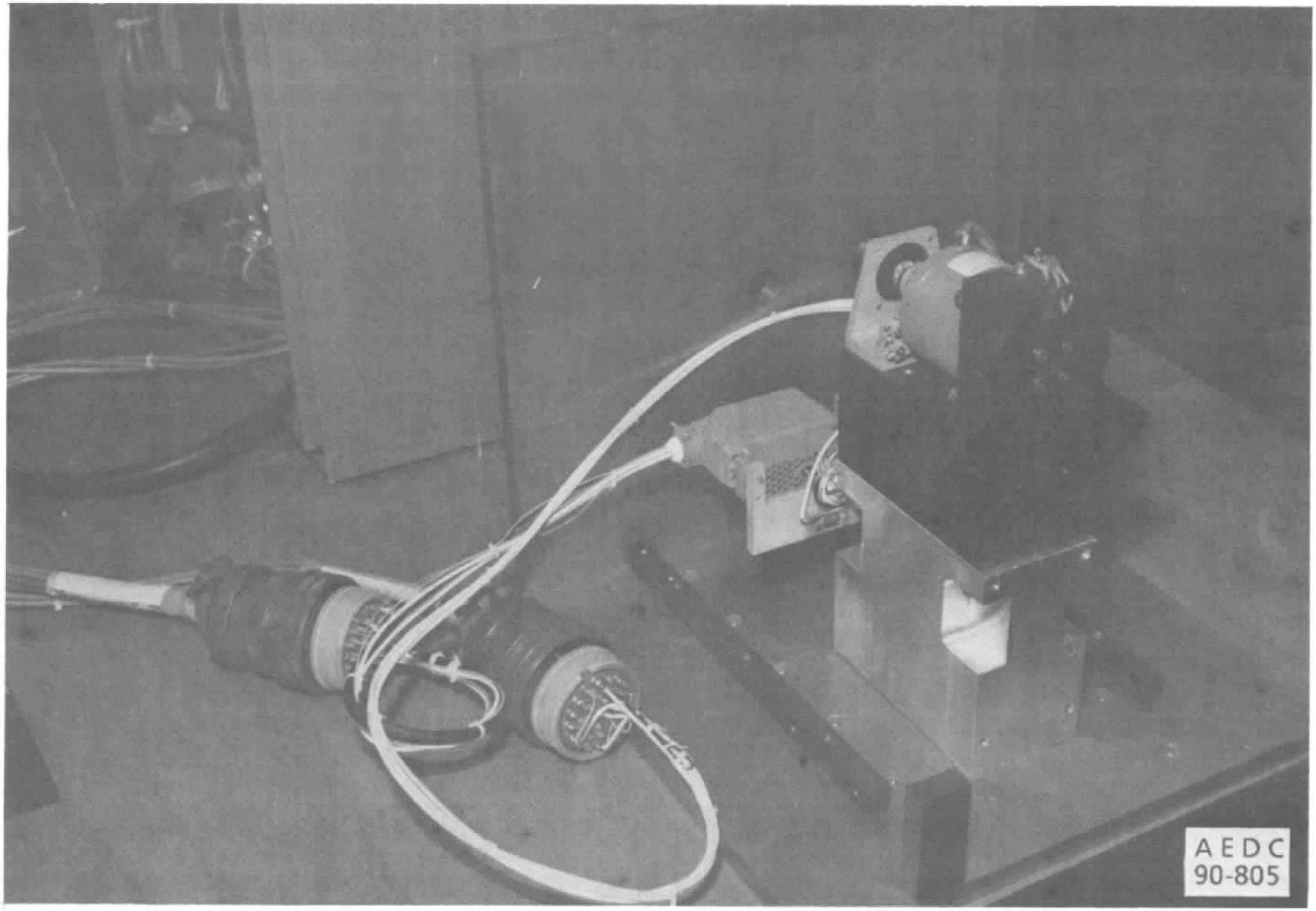


Figure 2. Standard Infrared Source installation on NIST mounting plate.

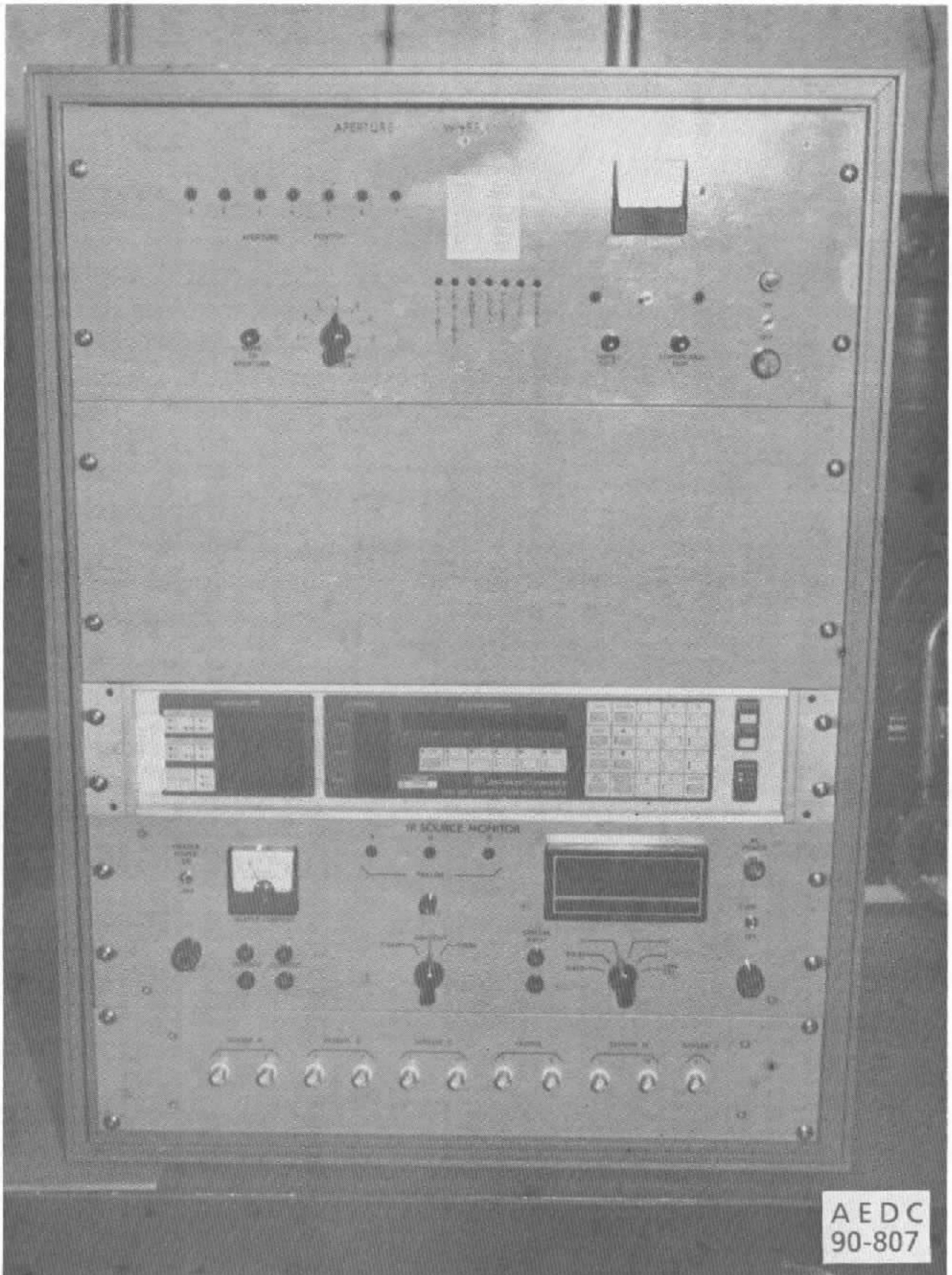
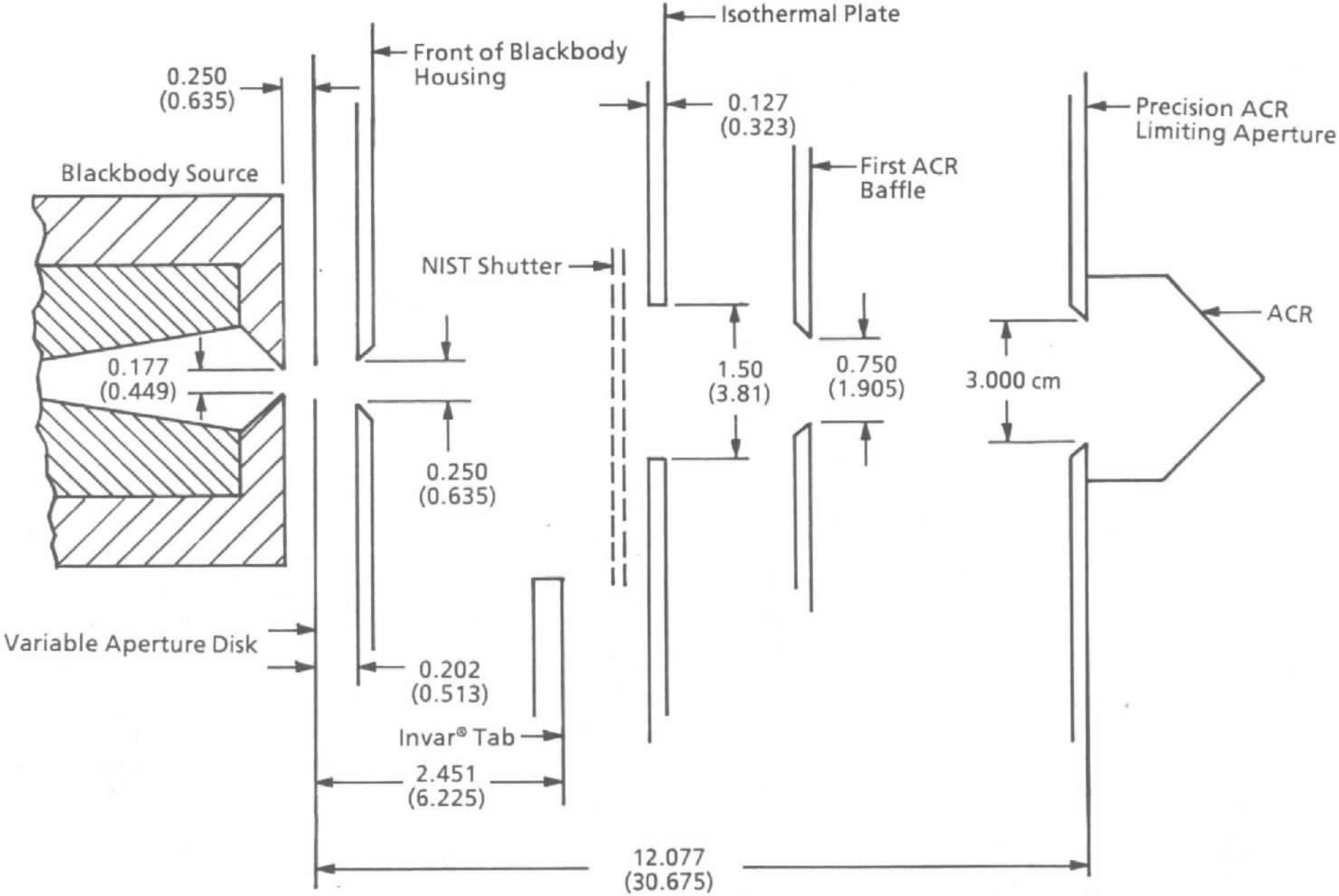


Figure 3. Standard Infrared Source instrumentation.



All Dimensions Are at Ambient Temperature (~300 K) in Inches.
Dimensions in ( ) Are Converted from Actual Measurements in cm.

Not to Scale.

Figure 4. Optical layout of the blackbody and ACR installation.

Table 1. Blackbody Output Aperture Diameters (Inches)

Wheel Position	Nominal Ambient	Measured	20 K	Standard Deviation (±)
1	0.0050	0.004933	0.004922	0.00005
2	0.0100	0.009987	0.009964	0.00005
3	0.1000	0.100053	0.099823	0.00005
4	Blank	---	---	---
5	0.0500	0.050043	0.049928	0.00005
6	0.0355	0.035510	0.035428	0.00005
7	0.0256	0.025600	0.025541	0.00005

Table 2. RTD Calibration Data

K95.CSV Temperature, K	Resistance, ohms	K97.CSV Temperature, K	Resistance, ohms	R2A91.CSV Temperature, K	Resistance, ohms
77.23	20.37400	77.23	20.29200	0.10	218.66470
100.0	30.06600	100.00	29.95600	2.10	219.91280
120.00	38.45600	120.00	38.33600	3.20	220.66170
140.00	46.74300	140.00	46.62500	4.19	220.88270
160.00	54.93900	160.00	54.83100	6.70	221.38060
170.00	59.00600	170.00	58.90500	7.80	221.62020
190.00	67.98500	190.00	67.00200	9.30	221.90970
210.00	75.09700	210.00	75.03300	11.10	222.29910
230.00	83.04800	230.00	83.00500	13.90	222.85830
250.00	90.94500	250.00	90.92100	16.40	223.39750
273.15	100.02200	273.15	100.01800	18.00	223.74690
295.11	108.56100	295.11	108.55900	23.40	224.84520
310.00	114.33900	310.00	114.35900	36.50	227.56110
330.00	122.04200	330.00	122.07200	49.70	230.58640
350.00	129.69800	350.00	129.73400	58.50	232.73310
373.47	138.62400	373.47	138.66400	65.10	234.40060
393.54	146.18600	393.54	146.21600	77.40	237.62730
410.00	152.38000	410.00	152.41900	150.00	255.10880
422.58	157.08300	422.58	157.11900	225.00	273.17110
523.15	194.09720	523.15	194.09720	297.04	290.52150
---	---	---	---	355.45	306.36690

Table 3. SIRS II Calibration Data — Sensor A Aperture 3 (Diameter at 20 K = 0.099823 in.)

Sensor A Data, K	Mean Radiance Temperature, K	Radiance Deviation, percent	Total Uncertainty (Radiance), percent
100.039	99.6	-1.775	2.8
150.007	150.0	-0.019	1.6
199.893	200.2	0.612	1.2
224.750	225.2	0.797	1.2
249.683	250.4	1.140	1.2
274.686	275.5	1.177	0.8
299.544	300.6	1.398	0.8
324.421	325.6	1.441	0.8
349.360	350.7	1.520	0.8
374.093	375.7	1.700	0.8
399.077	400.3	1.216	0.8